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DESIGN REFINEMENTS FOR A SUN-TRACKING SOLAR ENERGY RECEIVER HAVING A SPHERICAL REFLECTOR

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EXTENDED ABSTRACT

The solar energy collector, including a weightless balloon with sun-tracking means (USP 4126123), has been described previously[1]. This paper describes a number of design refinements which can be applied to the basic system.

For all sizes, the heat collection probe is structurally fixed as it passes through a dished, mirrored metal plate to which the balloon is attached. Probe collecting length is dia./4. At 30m dia., probe can be cantilevered ($\Delta = wL^4/8El$). At 60m dia., probe must have sun-end supported from balloon equator using stranded airplane cables ($\Delta = wL^4/185El$). At 90m dia. and 120m dia., a second set of cables is required ($\Delta = wL_a^4/185El = wL_b^4/76.8El$) where $La = (185/76.8)^{1/4} L_b = 1.25\ L_b$. At 150m three sets of cables would be needed ($L_b = L/3.25$) to limit deflection to less than 3 cm.

Probe O.D. is center coolant return tube diameter plus 4 cm for annular 10^{-7} Torr vacuum for thermal insulation. The vacuum pipe is part of the probe strong back together with 4 cm added for coolant supply channels. Concentration factors and probe diameter are 877(10 cm) for 30m dia., 1,759(12 cm) for 60m dia., 2,638(14 cm) for 90m dia. with progressively higher values at larger diameters. Concentration must greatly exceed 1,000 for receiver temperature to exceed modern steam plant levels [2] at maximum heat gain.

Probes are linear receivers. For the first dia./5 nearest balloon skin sunrays impinge at angles of 60-90° carrying 3/4 of the incident energy. The sun-end dia./20 has rays impinging at 0-60° carrying 1/4 of the incident energy. Coolant supply channels 5 cm wide by 2 cm high and 0.08 cm thick can be flat-wound for the dia./5 length and tilted so that the near leg rests at the far corner of the preceding wind over the last dia./20 to be at an angle of 70° to probe axis so that impingement is to 60-90°.

For thermal collectors channels would be stainless or better and outer seams would be welded. Coolant would be water to 400°K and eutectic liquid metal (NAK) at higher temperatures, to hold maximum pressures to 4 atmas so that mid-channel bulging will be less than 0.03 cm. Center tube sag would be prevented by wire hoop supports spot-welded to tube at 3m centers.

For photo-voltaic collectors, channels would be of fluorinated ethylene propylene (FEP) stock holding ribbons of photo-voltaic cells with seams sealed using the hot melt process. Coolant would be very pure, deionized water or highly refined heat transfer oil to act as the dielectric separator. The strong back pipe and center tube would be the electrodes for the dc power collection and be standard thickness aluminum. Aluminum wiring from cell ribbons to the center tube would penetrate wall of strong back pipe using

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encapsulated FEP feed-throughs. Wires would be welded to pipes. The annular space between outer pipe and center tube would be empty but not evacuated to save weight.

Fortuitously, the channel arrangements described earlier obviate the need for mushroom-type heads which, if used, could seriously depreciate the concentration factors. Probe end plates would be extended only enough to provide for terminating support cables.

Thermal collection requires selective surfacing to enhance absorption and inhibit re-emission of solar energy. To 600^{o}K, chrome oxide is adequate. At higher temperatures annealed copper oxide will do nicely. An alternate possibility is to bake the probe assembly at 900^{o}K for four hours in air which turns stainless steel black.

The balloon reflector buoyancy must offset the dead weight of all moving parts because these overhang the apex of the bases by tens of meters. It happens that balloons filled with dry nitrogen are just weightless at almost all diameters. Fill gas is obtained at the site by bleeding out oxygen cyrogenically using the Philipps cycle. Balloons are spherical or spheroid to save material and permit concentration of sunlight that is attainable using balloon manufacturing tolerances.

Coaxial spoilers may be needed to prevent direct upward channeling of heated gasses so as to impinge on the PVF film laminates of the reflective hemisphere at too high a temperature. This is particularly important close to the point of probe entry through the balloon skin. A coaxial tube of heat resistant glass, open-ended or sealed, and either evacuated or filled with dry nitrogen or a very dense transparent gas for the first dia./12, should insure balloon integrity in the early morning or late afternoon. When sun is high in the sky, convective heat loss will rise away from nearest balloon surface. The use of metal spoilers must be relegated to the outermost dia./12 portion of the probe in order not to block reflected sun rays.

All wind forces, which are considerable for balloons of large diameter, must be collected at the single sun-tracking pivot point. Earlier, the use of stranded aramid cable tethers in UV light-resistant sheaths was considered, but there is a simpler way which is also streamlined. The conic of tether cables is replaced by film laminates consisting of 0.005 cm thick opaque polyvinyl fluoride (PVF) reinforced by aramid mesh covered with a second 0.005 cm thick opaque PVF film. Maximum available panel width is 2m and as the focus point is approached more and more layers of laminate are used per strake to offset the intensifying stresses.

The sun-tracking pivot point will be located at the apex of a thin wall, 8 cm or Π in. thick concrete base which can have several levels and house a control room, fill gas and vacuum systems, coolant heaters, boilers, superheaters and reheaters, while the lowest level would be for turbine generators, condensers, cooling towers, feedwater pumps, switchgear, transformers, dc power supplies, and electrolyzers, some or all of which may be needed. Conical bases would do nicely but require elaborate slip forms. Parabaloid bases can be erected using the Binishell system[3]. This unique approach has double flexible forms. First, a concrete slab is placed at grade and cured. Then wet concrete is placed on overlapping reinforcement within springs on the bottom flexible form. The springs act like screeds to set proper concrete thickness. The top flexible form is then placed on the concrete and compressed air then pumps the wet concrete into its final shape as established by the tension of the springs and forms. The springs also act like dams while the mix is vibrated to insure uniform distribution and density. The initial operations require a small crew for two to three weeks. One to two hours after concrete placement, the parabaloid outer base is in place and maintained there until the concrete sets and gains strength. Similarly, a smaller parabaloid can be erected within the outer shell for large installations and forms for floors above grade can be hung on cables attached to the upper walls. The wind forces against the pivot point can be tremendous and one-half of the steel reinforcement must go into tension in any given direction to prevent displacement.

Balloons must face east in the morning, south at noon and then west. Most house lots are too small to permit this. Most condominiums, many apartment complexes, shopping centers and factories have sufficient land and could use a single unit of up to 30m diameter to augment their heating and cooling needs. Larger units, at 60 or 90m diameter operated a higher temperature, can be used in process plants to cogenerate electrical power and process steam. Still larger units can be used to generate steam at high temperatures required by the most efficient 3600 RPM steam-turbine generators [4]. The optimum unit cost is close to 90m diameter, but units of 120m or 150m might be justified in time.

In 1978 the estimated cost per m^2 was close to 50 USD over a wide range of diameters. Very small and very large diameters are not economical. Manufactured items have escalated 7% per year since then. Construction items (concrete bases) have escalated 10% but the use of the Binishell system or equal should reduce this item to 7% as well. Thus the present estimated cost is 60 USD per m^2 which is the same as 75 USD per m^2 in 1984. The capital cost for high temperature solar energy collection was estimated in 1979 to be 155 USD/Kwe and 68 USD/Kwt which is the same as 217 USD/Kwe and 95 USD/Kwt in 1984. Since a dual purpose solar-electric plant (DUPSEP) generating electrical power and hydrogen gas on a firm basis is initially of modest size (10 to 100 MW), a three-year lead time seems adequate. This collection system has two major benefits of immediate interest. The sunshine is "free" and excess hydrogen generated can be sold as fuel. Also there is minimal impact on land use. The concrete bases occupy about 5% of the surface while the rest can be used for grazing, farming or other low head room use.

References

1. F.F.Hall, "Solar, Geothermal, Hydrogen and Hydraulic Power," ASCE Journal of the Power Division, February 1978 and "Weightless Solar Energy Collection," First Brazilian Energy Congress, December 1978.
2. J.A.Duffie, W.A.Beckman, "Solar Energy Processes," p. 187, John Wiley and Sons, 1974.
3. Binishells International, San Francisco, Ca.
4. F.F.Hall, "Dual Purpose Solar-Electric Power Plants," MICAES II, 1977 and "More on Dual Purpose Solar-Electric Power Plants," MICAES III, 1979.